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SRS/STG-TR92-01

(NASA-CR-184247) ADVANCED LIFE SUPPORT
STUDY Final Report (Spectra Research
Systems) 46 p CSCL 06K

N92-14595

Unclass
53/54 0051133

FINAL REPORT

Advanced Life Support Study

September 3, 1991

(Contract No.: NAS8-38781)

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1.0 INTRODUCTION

This report documents the work performed by SRS Technologies for the National Aeronautics and Space Administration (NASA)/Marshall Space Flight Center (MSFC) under contract NAS8-38781, "Advanced Life Support Analyses". This work was performed in support of the Space Station *Freedom* (SSF) program and the Exploration Technology Program and builds on work initiated by NASA/MSFC under a previous contract with McDonnell Douglas Space Systems Company.

1.1 Background for Tasks

NASA is involved in a diversified array of space programs and technical activities. Under the Advanced Life Support Analysis contract, at least three of the Marshall Space Flight Center's MSFC ongoing activities were supported: SSF Evolution, the Exploration Technology Program (also known as Pathfinder), and a MSFC Clean Room Survey and Assessment. In each of these three activities, MSFC expressed a need for additional technical support and met the requirements through tasks under the Advanced Life Support Analysis contract.

Human presence in space requires that the basic functions necessary to support life must be provided in a manner consistent with the mission scenarios. The purpose of this present effort is to gain a better understanding of the future mission scenarios with regard to Environmental Control and Life Support System (ECLSS) requirements and constraints, and of the ECLSS technologies which may be used for these missions and their requirements. The mission scenarios which are the focus of this contract are the evolution of SSF over its lifetime and the Exploration Technology Program missions to return people to the Moon and to send them to Mars.

1.1.1 Space Station Freedom Evolution: ECLSS Evolution

During the course of its 30-year operational lifetime, SSF is expected to experience changes with regard to the number of crew, the number of modules (habitation and laboratory modules, etc.), the roles it will support (research facility, transportation node, etc.), and in other ways. Many of these changes will affect the ECLSS or may be affected by constraints imposed by the ECLSS. Also during this period technological advances will result in improved methods of performing the ECLSS functions.

As discussed below, one goal of this analysis is to enable ECLSS technologies to be replaced in a "transparent" manner by ensuring that the interfaces required for the replacements are provided for during outfitting of the modules. This requires that the interfaces be defined for the candidate replacement technologies for comparison with the baseline requirements and that requirements beyond those for the initial technologies be adequately identified.

Another goal is to ensure that modules can be added or relocated in a safe manner, which is consistent with the ECLSS requirements and constraints. Aspects of the ECLSS which are affected include intermodule ventilation, safe haven capabilities, and others. In order to avoid significant problems it is necessary to identify these effects before the modules are added or relocated.

The SSF Evolution tasks at MSFC were funded by the NASA Headquarters, Office of Space Flight, Code MT, via NASA's Langley Research Center (LaRC), which was the center for Environmental Control and Life Support Systems (ECLSS) Distributed Systems Evolution Studies. The levels and categories of funding were \$25,000 of fiscal year 1989 (FY89) funding and \$100,000 of FY90 funding. MSFC's objective was to take the baseline ECLSS design and evaluate the impact on ECLSS design due to changes in roles for SSF over 30 years, evaluate the impacts on ECLSS design due to technology advances, and evaluate issues related to a test bed for Lunar/Mars mission hardware. Then, using the results of each of these evaluations, identify the design requirements for an evolved ECLSS.

In the process of reaching these objectives, several SSF configurations were evaluated including: Eight-Man Crew Capability (EMCC) Baseline, EMCC Option C, Research Facility, Transportation Node, Fourteen Man Crew Capability (FMCC), Growth Option A, Growth Option B, and Growth Option C. The evaluations included the impacts on the evolution of ECLSS beyond EMCC. The impacts are further described in exhibit 1.1.1-1.

For fiscal year 1991, MSFC's objective was translated into three areas: technologies, implementation, and scenarios. Under technologies objectives, the study tasks were to define interface requirements and identify resupply requirements. Under implementation objectives, the study tasks were to describe "hooks and scars" and perform cost/benefit trade studies. Under scenarios objectives, the study tasks were to identify impacts on intermodule ventilation and identify ECLSS related module addition/relocation impacts. The results of the interface requirements task were to be incorporated into the resupply analysis and "hooks and scars" study tasks and then the results of all tasks would be used to support the cost/benefit analysis. Similarly, the results of the intermodule ventilation studies would support the module addition/relocation study.

Impacts on the Evolution of ECLSS Beyond EMCC

Common factors of the evolution scenarios

- Increased number of people (15 to 30 depending upon the scenario)
- Increased EVA (52 to 250 per year)
- Additional modules and pressurized volume (short modules plus nodes, logistics modules, "pocket" labs, etc.)
- Power availability (depends upon user requirements and production capacity)
- Safe haven considerations



Overall effects on the ECLSS requirements

- Increased capability
- Improved performance
- Added functions



Impacts on ECLSS design

- Reducing the need for expendables
- Increasing reliability of hardware
- Optimizing the recovery of mass
- Increasing autonomy of operation

Figure 1.1.1-1 Impacts on the Evolution of ECLSS Beyond EMCC

1.1.2 Exploration Technology Program: Advanced Instrumentation

Missions are being planned, for the early 21st century, to return people to the Moon and to send them to Mars. The Exploration Technology Program (ETP) will ensure that the technologies required for these missions will be developed in time to support them. These missions will, in some ways, have more stringent requirements for the ECLSS. Factors such as reliability will be much more important. Greater capabilities to monitor water and air quality and system performance, as well as increased autonomous operation, will also be required.

Toward this end, it is necessary to understand the instrumentation needs for these missions and the ECLSS technologies which may be used. Candidate instrumentation technologies which could be used, including new methods which are not yet commercially available, need to be identified and their potential applications identified. The instrumentation requirements of ECLSS technologies which may be used need to be identified and correlated with suitable instrumentation technologies.

1.1.3 Clean Room Survey and Assessment

It is anticipated that the clean room facilities at MSFC will be used in support of ECLSS testing. Therefore, a survey and assessment of the existing clean room facilities at MSFC is necessary to begin preparations for this anticipated support. The SOW was modified in order to support this study.

1.2 Contract Description

The Advanced Life Support (ALS) Analysis contract (NAS8-38781) was awarded on August 3, 1990. The total amount of this cost plus fixed fee contract, at the time of award, was \$196,268 and the period of performance was eight months (August 3, 1990 through April 3, 1991). The contract was modified on September 27, 1991, for the purpose of a MSFC Cleanroom Assessment and \$33,000 in additional funding was added to the total value of the contract. On February 20, 1991, the contract was modified to do additional ECLSS Evolution work and \$49,728 was added to the total value of the contract. The period of performance of the contract was extended until July 3, 1991. On July 12, 1991, an additional \$9,000 was added to the contract for ALS database work and the period of performance was extended until September 3, 1991. On July 31, 1991, an extension of the period of performance until January 3, 1992, was requested and is currently being processed.

1.2.1 General Description

The scope of the original statement of work (SOW) called for SRS to support ongoing activities at MSFC in relation to the investigation of advanced life support technologies for use on future manned missions through analysis, assessment, and refinement of computer tools. Analysis and assessment support was to involve characterizing the life support environment for future manned missions, developing requirements and specifications at the system and subsystem level, optimizing the life support system for each scenario under consideration, and assessing the impact of providing the capability for evolutionary replacement of life support technologies. The ongoing related activities at MSFC at the time this contract was awarded, were in the areas of ECLSS Evolution and Advanced Instrumentation. The ECLSS Evolution activities were expected to yield a "Hooks and Scars" impact definition, a Life Support Database, and computer tools. Advanced Instrumentation activities were expected to yield a definition of the instrumentation environments and instrumentation requirements. The overall objectives of the contract were to continue the ongoing studies, assess the Space Station Freedom (SSF) ECLSS prior to the Preliminary Design Review (PDR), define development needs of instrumentation technology, and redefine the instrumentation environment. The guidelines and assumptions to be followed by this contract

included an initial emphasis on broadbrush studies and then focusing on detailed studies of particular scenarios.

The tasks which were identified in the original SOW were split into to phases; Phase 1 beginning at contract start date (CSD) and ending three months into the contract and Phase 2 starting at three months and ending at end of eight months after CSD. During Phase 1, five subtasks including a literature survey, ALS Database Development, computer tool development, ECLSS Evolution tasks (comparative analysis, cost/benefit trade studies, and recommendation and conclusions), and advanced instrumentation studies (P/C CLSS selection) were identified. During Phase 2, realtime sensor requirements and specifications, for each focused case study, were to be developed along with detailed requirements and application specifications for chemical composition monitoring technology. Exhibit 1.2.1-1 below summarizes the original SOW.

1.2.2 Part 1 Description

Soon after contract award, events dictated that the original emphasis of the SOW be revised. A three month assessment of the SSF ECLSS was originally planned, however, since the SOW was written prior to the 90 day Space Exploration Initiative (SEI) study, the rebaselining and rephasing of SSF was underway, and PDR occurred before contract award, a revised emphasis was developed by MSFC. At the orientation meeting, SRS was presented with three questions and two activities reflecting a revised SOW emphasis. The first question was, how can the transition from a Physical/Chemical (P/C) be achieved? The second and third questions were related to Advanced Instrumentation; "what sensors and monitors are needed for a P/C- CELSS hybrid system?", and "how could a CELSS be automated and what controls are needed to to so?". SRS was also directed to conduct SSF Evolution studies and to revise and develop computer tools.

In addition to ECLSS Evolution and Advanced Instrumentation tasks, the MSFC Clean Room Survey and Assessment was also performed during this same time period.

In order to simplify the discussion of the accomplishments, the directives described in the previous paragraph will be henceforth referred to a Part 1. The accomplishments under Part 1 are described by four categories: P/C->Hybrid->CELSS Evolution, SSF Growth Trades, Computer Tools and Advanced Instrumentation. Under the P/C->Hybrid->CELSS Evolution category, technology development and schedule constraints were identified, mass payback implications were identified, and system integration issues were identified. Under the SSF Growth trades topic, growth configurations were identified, intermodule ventilation trades were perform ed, and interconnectivity recommendations were made. Under computer tools, plant chamber spreadsheets models were developed, space station growth intermodule ventilation spreadsheets were developed, and the development of an "in house" CASE/A capability was pursued. A detailed

Scope:

- Support ongoing activities at MSFC relating to the investigation of advanced li support technologies for use on future manned missions through analysis, assessme and refinement of computer tools.

- Analysis and assessment support will involve

- 1) characterizing the life support environment for future manned missions,
- 2) developing requirements and specifications at the system and subsystem level,
- 3) optimizing the life support system for each scenario under consideration, and
- 4) assessing of the impact of providing the capability for evolutionary replacement of li support technologies.

Background:

- Related ongoing activities at MSFC fall into to categories: ECLSS Evolution an Advanced Instrumentation

- ECLSS Evolution activities are expected to yeild a "Hooks & Scars" impact definition, Life Support Database, and computer tools. Advanced Instrumentation activities . expected to yield a definition of the instrumentation environments and instrumentati requirements.

Objectives:

- Continue the ongoing studies.
- Assess SSF ECLSS prior to PDR
- Define development needs of instrumentation technology
- Redefine the instrumentation environment

Guidelines and Assumptions:

- Initially emphasize broadbrush studies then focus on detailed studies of particul scenarios.

Tasks:Phase 1 (Starting at CSD - Ending at 3 months)

- a) Literature Survey - Review and expand existing literature survey.
- b) ALS Database Development - Expand the existing ALS database.
- c) Computer Tool Development - Existing models will be refined and new models constructed as required.
- d) ECLSS Evolution Tasks
 - 1) Comparative Analysis - Comparative analysis will be performed using the computer tools. For each SSF Evolution scenario, technologies will be prioritized and an optimized ECLSS chosen
 - 2) Cost/Benefit Trade Studies - The cost of providing "hooks & scars" for the IOC SSF will be traded against the potential gains of each evolution path and the benefits of transparent ECLSS evolution
 - 3) Recommendations and Conclusions
- e) Advanced Instrumentation
 - 1) P/C CLLS Selection - Define the instrumentation working environment.

Phase 2 (Starting 3 months - Ending at 8 Months)

- 2) Real Time Sensors - Develop requirements and specifications for each focused case study.
- 3) Chemical Composition Monitoring Technology - Develop detailed requirements and applications specifications.

Exhibit 1.2.1-1 A Summary of the Original Statement of Work

discussion of each of these accomplishments is presented in the following sections. The schedule which was followed is present in Exhibit 1.2.2-1.

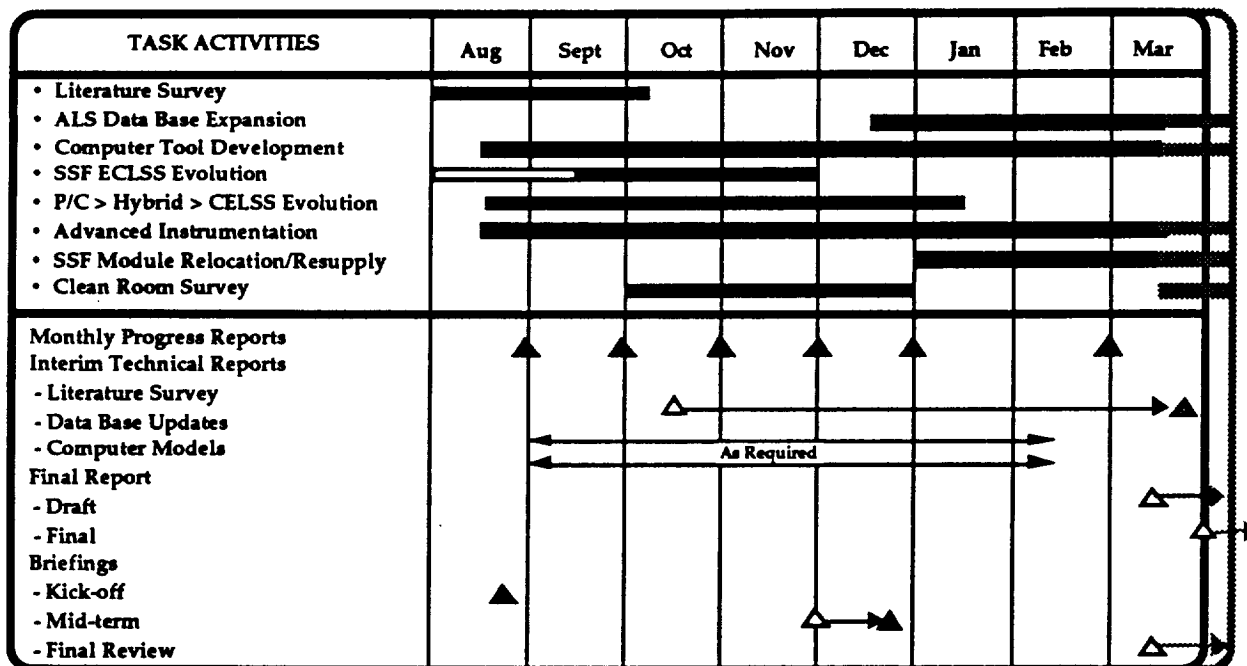
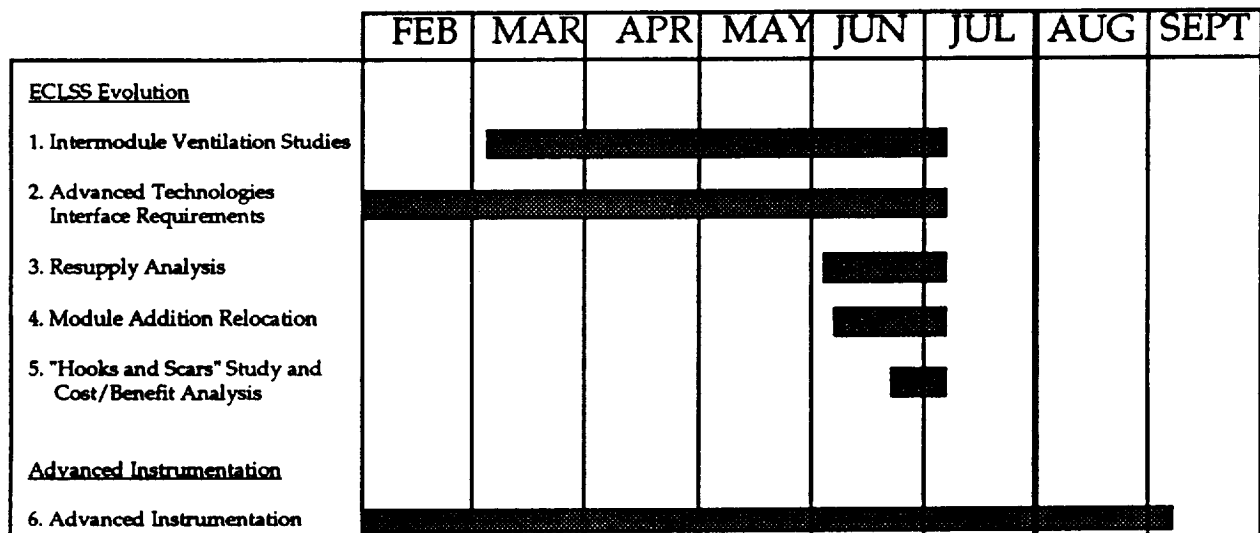


Exhibit 1.2.2-1 Part 1 Schedule and Milestones

1.2.3 Part 2 Description

Part 2 refers to the period of time starting with the end of Part 1 until September 3, 1991. During this period, five tasks under the ECLSS Evolution category were undertaken. These tasks included Intermodule Ventilation Studies, Advanced Technologies Interface Requirements, Resupply Analysis, Module Addition Relocation, and "Hooks and Scars" Studies. Under the category of Advanced Instrumentation, further development of the ALS Sensors database was pursued. Exhibit 1.2.3-1 summarizes the Part 2 tasks and accomplishments. Exhibit 1.2.3-2 is the schedule which was followed for Part 2.

PART 2 TASKS	PART 2 ACCOMPLISHMENTS
<u>ECLSS Evolution</u>	<u>ECLSS Evolution</u>
1. Intermodule Ventilation Studies	1. Developed and delivered algorithms, analysis results, and computer programs for 8 SSF Evolution Concepts.
2. Advanced Technologies Interface Requirements	2. Developed and delivered an ECLSS Technologies Interfaces Database.
3. Resupply Analysis	3. Gathered, compared, and identified inconsistencies in ECLSS Technology resupply data. Developed guidelines and procedures for comprehensive logistics resupply analyses.
4. Module Addition Relocation	4. Recommended studies to insure that critical resources and ECLSS functional requirements (including safe haven requirements) are maintained during SSF Evolution.
5. "Hooks and Scars" Study and Cost/Benefit Analysis	5. Identified and compared the rack level interfaces of the baseline O2 Generation subsystem (SFWE) with the alternative subsystem (SPE).
<u>Advanced Instrumentation</u>	<u>Advanced Instrumentation</u>
6. Advanced Instrumentation	6. Reviewed and revised the existing Sensors Database structure. Reviewed, verified, and modified sensors data.

Exhibit 1.2.3-1 Part 2 Tasks and Accomplishments**Exhibit 1.2.3-2 Part 2 Schedule**

1.2.4 Summary of Activities

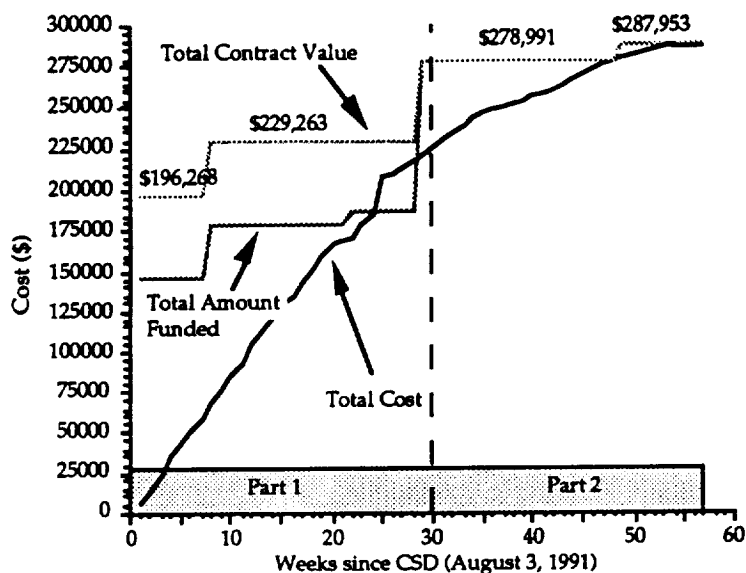
A summary of the overall contract activities and status is presented in Exhibit 1.2.4-1. Approximately 79 percent of the contract funding was spent during the accomplishment of Part 1. During Part 1, the contract was modified once for the purpose of the implementation of clean room survey results to improve capabilities for advanced ECLSS studies (Modification #2). An

orientation meeting and a midterm briefing also occurred during Part 1. Regular monthly progress reports were published along with two technical reports, a intermodule ventilation and water distribution study and an interim engineering report. The interim engineering report served as the unofficial end of Part 1.

Early in Part 2, SRS project leadership changed from E. E. (Sandy) Montgomery to James C. Pearson, Jr. Also, the contract was modified for additional ECLSS Evolution and Advanced Instrumentation studies, and was further modified in July 1991, for additional Advanced Instrumentation work. The period of performance was extended from April 3, 1991 until July 3, 1991, and then until September 3, 1991. Approximately 21% of the total contract funding was spent in part 2. Copies of the computers tools developed under this contract have been delivered to NASA along with preliminary results from the tasks. Regular monthly progress reports were also delivered.

1.3 Organization of this Report

This report is divided into five parts: an introduction, tasks descriptions, overall conclusions, references, and appendices. The first four parts are presented in Volume 1 and the appendices are presented in Volume 2. Each of the reports in the appendices are considered to be "stand alone" reports.

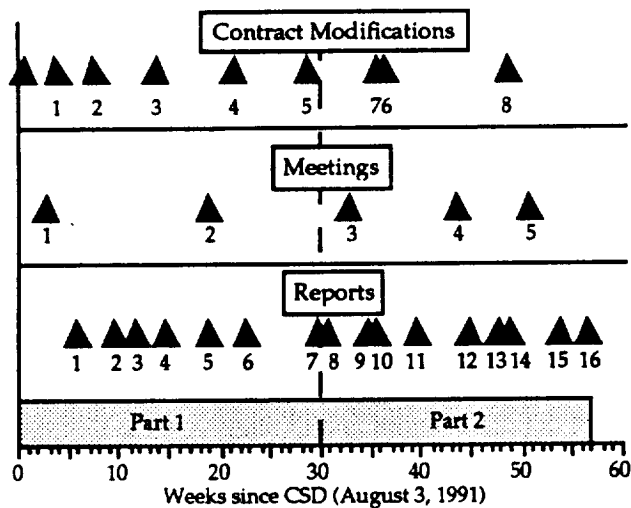


Contract Costs Thru August 16, 1991

Costs	% of Total Cost
Part 1 \$226,784	79%
Part 2 \$ 61,102	21%
Total \$287,868	

Amount Spent as of August 16, 1991

\$287,868



Contract Modifications

1. Cleanroom Announcement (8/28/90)
2. Cleanroom Award, \$33K, (9/27/90)
3. ECLSS Evol Task Announcement (11/7/90)
4. Incremental Funding, \$9K, (1/3/91)
5. ECLSS Evol. Task Award, \$49K, & Incremental Funding, \$41K (2/20/91)
6. No Cost Extension Until 7/3/91 (4/17/91)
7. ALS Sensors DB Announcement (4/5/91)
8. ALS Sensors DB Award and Extension until 9/3/91, \$9K (7/12/91)

Significant Meetings

1. Orientation (8/24/91)
2. Midterm (12/18/91)
3. SRS Management Transition (3/21/91)
4. Status (6/6/91)
5. Review (7/26/91)

Reports

1. August 90 PR
2. September 90 PR
3. Ventilation Study (10/24/90)
4. October 90 PR
5. November 90 PR
6. December 90 PR
7. Interim Engineering Report & End of Part 1 (2/28/91)
8. Jan-Feb 91 PR (2/28/91)
9. New SRS Project Manager (4/1/91)
10. March 91 PR
11. April 91 PR
12. May 91 PR
13. Draft Tasks Reports (7/3/91)
14. June 91 PR
15. July 91 PR
16. Final Report & End of Part 2 (9/3/91)

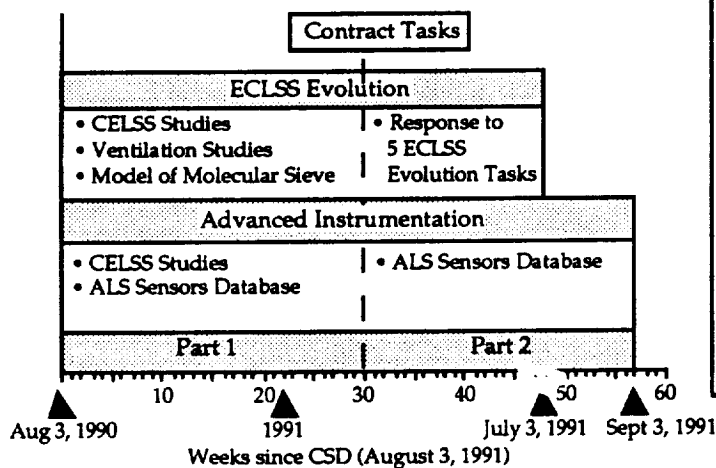


Exhibit 1.2.4-1 Advance Life Support Analysis Contract Summary

2.0 TASKS DESCRIPTIONS

2.1 Introduction

This section of the report contains summary reports on each of the eight task undertaken by this contract. Each summary report includes a statement of the task which demonstrates the correlation with the statement of work, a summary description of the work done under the respective task, and a summary of the results of the task.

2.2 Task 1 - Advanced Instrumentation: Evaluation of a CELSS

2.2.1 Statement of Task

The SOW presented in Exhibit 2.2.1-1 defines the tasks to be performed under Task 1 - Advanced Instrumentation. As previously discussed, the emphasis of this task was redirected due to circumstances at the time of contract award. While P/C CLLS were modeled and analyzed, bioregenerative CELSS were also studied, modeled, and analyzed so that trade studies comparing a P/C CLLS with a bioregenerative CELSS could be performed. The section of the SOW related to this task is presented below.

e. ADVANCED INSTRUMENTATION

1. P/C CLLS SELECTION -- In order to develop requirements for instrumentation, the working environment for that instrumentation shall be defined. The contractor shall define this environment by selecting an optimized Physical/Chemical Closed Loop Life Support (P/C CLLS) system for each manned exploration mission under focused consideration by the Office of Exploration (examples are the Lunar Evolution Case Study, Mars Evolution Case Study, and Mars Expedition Case Study). Other factors which influence the instrumentation working environment shall be identified, including but not limited to the gravity environment, activities within the habitable environment such as biological and material experiments, and mission constraints such as power, weight, and volume criticality. Results of the earlier efforts will provide optimized P/C CLLS systems for selected focused case studies; the complete environment definition will also be identified for these case studies. The environment definitions shall be used in tasks e.2 and e.3 below to develop requirements and specifications for each focused case study. Also, in the event of a change in mission definition, studies will be updated as required. The existing study results will be reviewed for completeness and assumptions reviewed for appropriateness, and any discrepancies rectified.

2. REAL-TIME SENSORS -- Detailed requirements and specifications for real-time sensors shall be developed for each focused case study based on the environment definition developed in task e.1 above. Results of earlier efforts shall be verified and integrated. Existing Space station baselined sensors shall be evaluated in accord with the specifications to identify further development needs. A technology survey of present and emerging sensor technologies shall be performed to select highly leveraging instrumentation and control technologies for each P/C CLLS option supporting selected mission scenarios.

3. CHEMICAL COMPOSITION MONITORING TECHNOLOGY -- Develop detailed requirements and application specifications for instrumentation to be used for determining the composition of complex mixtures that are considered likely to be present in each of the environments defined in task e.1., P/C CLLS SELECTION. Results of earlier efforts shall be verified and integrated. Space Station Baselined chemical composition monitoring technology inadequacies shall be assessed against requirements. Application specifications shall address both the required monitoring functions and compatibility with the overall P/C CLLS control system.

Exhibit 2.2.1-1 SOW Sections Related to Advanced Instrumentation

2.2.2 Description of Work Done

The Interim Engineering Report provides a narrative description of the trades studies performed during Part 1 of the Advanced Life Support Analysis study. A mid-term review was held at the offices of SRS Technologies in Huntsville, Alabama on December 18, 1990. Section 2 of the report describes the study results presented in the technical briefing. After review by NASA, a number of questions were raised about the material presented, primarily directed toward further explanation of the results and comparison with the results achieved by others. Section 3 of the report responds to those questions and action items. The report concludes with Section 4, which summarizes conclusions drawn from the resulting data. The Interim Engineering Report is presented in Appendix A.

2.2.3 Results

A complete report of the results is presented in the Interim Engineering Report found in Appendix A. Below, in figures 2.2.3-1 and 2.2.3-2, are summary conclusions for both P/C>Hybrid>CELSS Evolution and Advanced Instrumentation.

- Regardless of the degree of hybridization, P/C components are needed to balance biological processes in a space life support system for humans.
- Very different P/C processes are needed depending on the degree of hybridization.
- The CO₂ reduction reaction determines the optimum degree of hybridization for gas exchange:
- For fast rapid build-ups like adding 4 lunar base crew every 2 years, system mass growth has stronger affect on payback than resupply and breakeven points are pushed out beyond reasonable planning horizons.
- In-situ manufactured oxygen is not needed for Lunar Base life support when the system is above 85% hybrid (i.e. a mostly bioregenerative system) except for oxygen makeup due to leakage and/or airlock loss.
- Factors critical to early breakeven points in hybrid versus P/C ECLSS are the power penalty for plant chamber lamps, spares/maintenance resupply mass for plant chamber subsystem, and an assumption on the required daily food mass per crew (4.5 vs. 1.84 lb).

Exhibit 2.2.3-1 Summary Conclusions for P/C>Hybrid>CELSS Evolution

- Plant transpiration as a method of water recovery has significant benefits if condensate quality meets contamination standards, contamination of plant chamber with biocides can be avoided, and the same plants can provide food, gas exchange, and water recovery.
- Sensor requirements exist for bioregenerative systems beyond those of P/C systems since plant chamber harvest is new process stream for a space system, higher plants may require life support to symbiotic microbial life, and current microbial monitoring technology unlikely to be sufficient.
- Available technology development time is short for bioregenerative systems since current technology maturity levels are low, early deployment of bioregenerative systems is requested in most SEI plans and due to the increased emphasis in the technology development programs which are needed.
- Hybrid and CELSS involve significant new control challenges such as the highly adaptive systems and controllers required by ECLSS evolution, the compensation for human and plant metabolic dynamics, the more complex interactions with new processor types and streams, and due to the "Man System Integration"-type standards needed for higher plants.
- In terms of the potential automation benefits likely for farming and food preparation, the value of benefits is difficult to assess until the system concepts mature. The benefits may result from reduction in crew labor rather than safety or lack of human ability.

Exhibit 2.2.3-2 Summary Conclusions for Advanced Instrumentation

2.3 Task 2 - ECLSS Evolution: Intermodule Ventilation Study

2.3.1 Statement of Task

The objective of this task was to evaluate intermodule ventilation for potential arrangements of additional habitation and laboratory modules, pocket labs, logistics modules, etc. The cases to be studied included adding modules both in plane with the original modules and out of plane, both parallel and transverse. The EMCC (Eight-Man Crew Configuration) was to be used as the baseline. Ultimately, the study should identify any restrictions on the locations of additional modules.

The section of the SOW relating to Task 2 is the revised subparagraph d.1 and is presented in the "plain text" and "underlined text" of subparagraph d.1 in Exhibit 2.3.1-1 below. The original SOW is presented in the "plain text" below. The "bold face" text reflects the modification for Clean Room Assessment. The "underlined text" reflects the modification for additional ECLSS Evolution studies.

d. ECLSS EVOLUTION TASKS

1. **COMPARATIVE ANALYSES** - In order to evaluate the various ECLSS evolution options for various growth scenarios, a series of comparative analyses will be conducted. The Space Station Freedom ECLSS design and existing groundbased clean room facilities will be used as a baseline for comparison. Limited comparative analyses from the ongoing study will be the starting point. Using the computer tools developed in the previous task, trade studies of a range of ECLSS evolution options shall be performed. Both qualitative and quantitative factors shall be considered and the variances from the baseline Space Station ECLSS shall be determined. For each Space Station evolution scenario, technologies shall be prioritized according to trade study results, and an optimized ECLSS shall be chosen. **In addition, this comparison will include an evaluation of the facilities, equipment, technologies, and procedures used to maintain specified environments in typical aerospace industrial areas.** As a starting point, a survey will be performed of the clean room facilities at the Marshall Space Flight Center (MSFC). The survey shall address existing MSFC clean room facilities, equipment, operations, and maintenance procedures. Data shall be collected, compared, and cataloged for each facility, including: (a) engineering/design, (b) construction materials, (c) work stations, (d) contamination control, (e) particulate elimination, (f) entry systems equipment, such as air shower tunnels, air curtains, and air locks, (g) garment storage, (h) static charge control, (i) handling equipment, and (j) instrumentation, including

particle counters, air velocity and temperature meters, electrostatic locaters, and temperature/humidity recorders. Cleaning equipment and supplies shall be cataloged into a comprehensive electronic data base that will relate the physical characteristics, condition, and operational status of each clean room facility at MSFC. Available maintenance records for existing clean room equipment shall be reviewed and, if necessary, updated and included in the comprehensive clean room data base. Recommendations shall be made concerning needed improvements or upgrades, equipment purchases, repairs, and enhancements required to assure an efficient and orderly evolution of MSFC clean room environmental control facilities. Results of this ground-based survey will serve as an analog to support the evolution of spacecraft ECLSS for future manned space programs. As Space Station Freedom evolves, pressurized modules (including Hab, Lab, and logistics modules and pocket labs) will be added and relocated and interior rearrangements may be made. The effects of these changes on the ECLSS shall be evaluated including: additional interconnections required, effects on intermodule ventilation (including any restrictions on locations of additional modules), and other factors related to module location or relocation. Resupply requirements affect the operation of Space Station Freedom with regard to crew time required for maintenance and additional flights to bring the necessary supplies. ECLSS evolution shall be evaluated for resupply requirements and recommendations for reducing the logistics weight and volume shall be made."

2. COST/BENEFIT TRADE STUDIES - This task will trade the costs of providing hooks and scars for the IOC Space Station against the potential gains of each ECLSS evolution path and the benefits of allowing transparent ECLSS evolution for the evolutionary Space Station.

3. RECOMMENDATIONS AND CONCLUSIONS -- Summarize total recommendations for growth and ECLSS growth scenario recommendations quantifying potential gains of each for each evolutionary scenario.

Exhibit 2.3.1-1 SOW Sections Related to ECLSS Evolution

2.3.2 Description of Work Done

Two distinct activities were undertaken related to studies of intermodule ventilation. During part 1, a study was conducted and a report entitled "An Investigation of the Growth of Intermodule Ventilation Systems and Water Distribution Systems to Accommodate the Addition of a Hab and Lab Module with Nodes to the Assembly Complete SSF Configuration" was produced. The

purpose of this investigation was to determine if the intermodule ventilation (IMV) systems, and water distribution systems of SSF modules and nodes should be connected as they are interfaced with those already in operation. This report is offered in Appendix B.

During part 2, intermodule ventilation studies were performed for various SSF configurations to identify restrictions on the locations of additional modules. Some of the concepts studied came from LaRC. The LaRC SSF growth concepts resulted from studies to evaluate module patterns considering assembly and Shuttle payload transfer operations and from comparisons of operational complexity among the module pattern options. Eight different growth configurations of the SSF were analyzed including the Eight Man Crew Configuration (EMCC), the Research Configuration, the Research and Transportation Configuration, the Fourteen Man Crew Configuration (FMCC), Option C, Growth Option A, Growth Option B, and Growth Option C. The EMCC configuration served as the baseline and all other configurations were built up from this configuration. A complete report on the part 2 activities along with a complete set of presentation charts for the part 2 study, are presented in Appendix B. Computer tools to provide analysis of each configuration were developed and working copies were delivered to MSFC.

2.3.3 Results

The work accomplished under this task involved the determination and evaluation of CO₂ concentrations for several configurations, assuming steady state conditions. Parallel and "racetrack" flow paths, several AR locations, and various cases where crew were concentrated in modules or evenly dispersed throughout the configuration were trade study variables. The results of CO₂ concentrations indicated that parallel flow patterns were generally better than racetrack flow pattern for keeping CO₂ concentration within acceptable limits. Computer models for each configuration studied were developed and working copies delivered to NASA.

Previous studies indicated that racetrack flow patterns were better than parallel. The differences in the results may be due to differences in locations of the AR subsystems and crew. Further study using CASE/A to analyze transient conditions is needed.

A task report and a complete set of presentation charts and results is presented in Appendix B.

2.4 Task 3 - ECLSS Evolution: Advanced Technologies Interface Requirements

2.4.1 Statement of Task

Building on the ECLSS technologies database initiated by McDonnell Douglas Space Systems Company (MDSSC), for each ECLS technology, identify and describe the required interfaces including: fluid interfaces (flow rates, composition, temperature, pressure, etc.);

electrical interfaces (average and minimum/maximum power levels, number of power lines, etc.); data/control interfaces (number of data/control lines, likely data rates, etc.; resupply (types of expendables including filters, reactors, etc. and the quantities). Refer to Exhibit 2.3.1-1 for the SOW relating to this section.

2.4.2 Description of Work Done

An Advanced ECLSS Technology Interfaces Database was developed primarily to provide ECLSS analysts with a centralized and portable source of ECLSS Technologies interface requirements data. In addition to studying interface issues, this database provides data to the resupply analysis task and the "Hooks and Scars" study and Cost/Benefit analysis task. The database contains 20 technologies which were previously identified in the MDSSC ECLSS Technologies database. The primary interfaces of interest in this database are fluid, electrical, data/control interfaces, and resupply requirements. Each record contains fields describing the function and operation of the technology. Fields include: an interface diagram, a description, applicable design points and operating ranges, and an explanation of data, as required. A complete set of data was entered for six of the twenty components including Solid Amine Water Desorbed (SAWD), Thermoelectric Integrated Membrane Evaporation System (TIMES), Electrochemical-Carbon Dioxide Concentrator (EDC), Solid Polymer Electrolysis (SPE), Static Feed Electrolysis (SFE), and BOSCH. Data for these 6 components has come from the ECLSS Technology Demonstrator Hardware (alias Technology Demonstration Program (TDP)) data books, primarily the Interface Control Documents (ICD). Additional data was collected for Reverse Osmosis Water Reclamation - Potable (ROWRP), Reverse Osmosis Water Reclamation - Hygiene (ROWRH), Static Feed Solid Polymer Electrolyte (SFSPE), Trace Contaminant Control System (TCCS), and Multifiltration Water Reclamation - Hygiene (MFWRH). A summary of database contents is presented in Exhibit 2.4.2-1. Database printouts of the six completed data records are presented in Appendix E. With the database structure and report forms already developed, and pending the availability of data, the remaining data should be entered. The database is resident on the Macintosh computer with Foxbase+/Mac as the host software. Copies of the database have been delivered to NASA.

ECLSS Technologies Interface Data			Baseline ECLSS Technology	Interfaces Data Collected	Data in Interfaces Database
ECLSS Subsystem	Function	Technologies			
AR	CO ₂ Removal	4-Bed Molecular Mole Sieve (4BMS)	✓		
		2-Bed Molecular Mole Sieve (2BMS)			
		Lithium Hydroxide Canisters (LiOH)			
		Solid Amine Water Desorbed (SAWD)		✓	✓
		Electrochemical Depolarized CO ₂ Concentrator (EDC)		✓	✓
		Air Polarized CO ₂ Concentrator (APC or EDC W/WO Hz)			
	CO ₂ Reduction	Bosch		✓	✓
		Sabatier	✓		
		Advanced Carbon Reactor (ACR)			
	O ₂ Generation	Static Feed Water Electrolysis (SFWE)	✓	✓	✓
		Solid Polymer Electrolysis - Liquid Anode Feed (SPE)		✓	✓
		Water Vapor Electrolysis (WVE)			
		Static Feed Solid Polymer Electrolyte (SFSPE)		✓	
	O ₂ Generation/CO ₂ Reduction	CO ₂ Electrolysis			
	Airborne Contaminant Control	Trace Contaminant Control System (TCCS)		✓	
WRM	Urine Recovery	Thermoelectric Integrated Membrane Evaporation Subsystem (TIMES)		✓	✓
		Vapor Compression Distillation (VCD)	✓		
		Air Evaporation System (AES)			
	Water Processing	Vapor Phase Catalytic Ammonia Removal (VPCAR)			
		Reverse Osmosis (RO) *			✓
		Multifiltration (MF) *	✓	✓	
		Electrodeioniation			

* Data has been collected for ROWR-Potable, ROWR- Hygiene, and MFWR-Hygiene

* Data has been collected for ROWR-Potable, ROWR- Hygiene, and MFWR-Hygiene

Exhibit 2.4.2-1. Summary of Interface Database Contents

The gathering of technologies interfaces data was actively pursued but the applicable data is scarce. For the six entries in the interfaces database, we were able to locate lists of the ORU's but no real resupply data such as weights, rates, volumes, Mean Time to Repair (MTTR) and Mean time Between Failure (MTBF), was located.

2.4.3 Results

Additional data was added for the well defined technologies which were included in the technology demonstration program at MSFC. Data was collected for the technologies included in the Technology Demonstration Program at MSFC. The database includes ECLSS subsystems from the Atmosphere Revitalization (AR) and Water Recovery Management functional areas. Printouts of the database contents are given in Appendix C.

2.5 Task 4 - ECLSS Evolution: Resupply Analysis

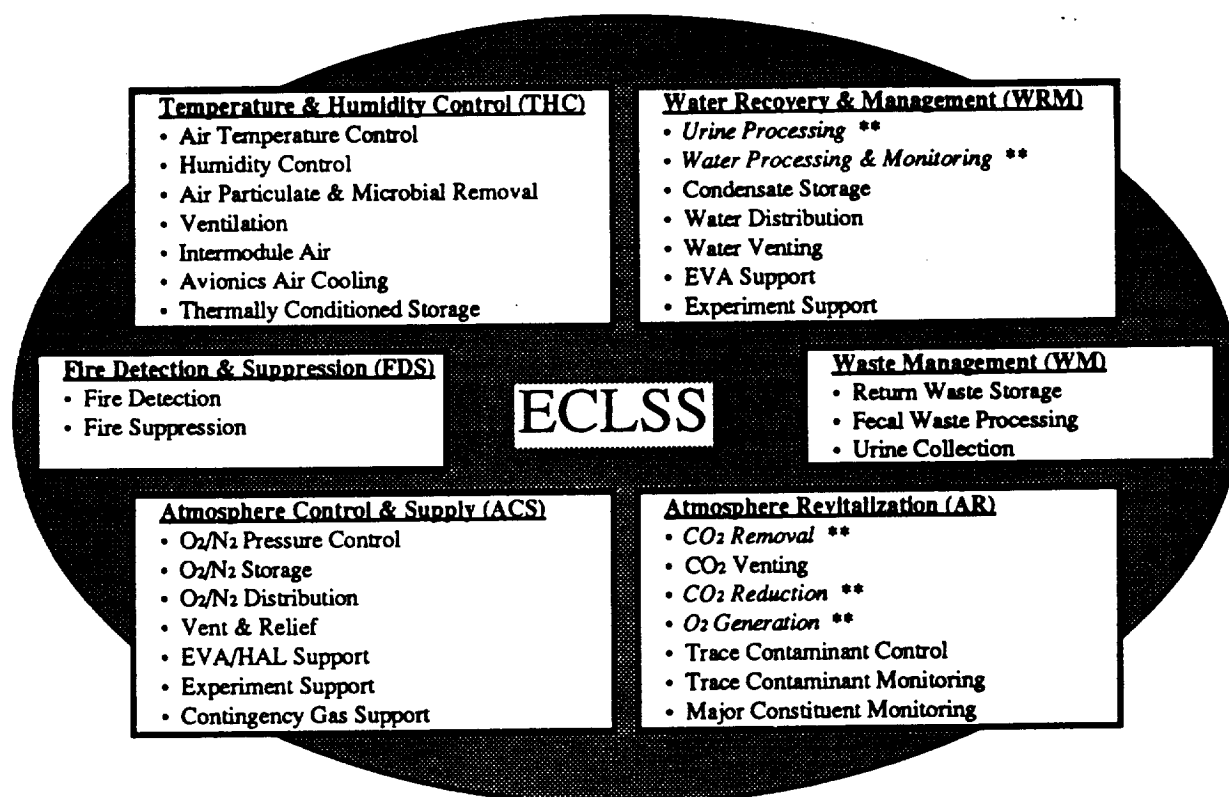
2.5.1 Statement of Task

Based on the resupply requirements for each technology identified in Task 2 (the ECLSS Evolution: Intermodule Ventilation Study), this task called for the estimation of the logistics requirements to support each technology including analyses for different phases of Space Station *Freedom* evolution in which there will be different crew sizes, considering the potential for "economies of scale." Also, methods of reducing logistics weight and volume were to be recommended. Refer to Exhibit 2.3.1-1 for the section of the SOW relating to this task.

2.5.2 Description of Work Done

The purpose of this task was to determine the logistics requirements to support each ECLSS technology described in the Technology Database developed by McDonnell Douglas Space Systems Company (MDSSC) and to analyze the logistics requirements, for each technology, for different phases of the Space Station Freedom evolution in which there will be different crew sizes. Due to the lack of required data and inconsistency in the data gathered the effort focused on development of guidelines and procedures for a more meaningful technologies logistics requirements analysis. In addition, some issues to consider for reducing logistics weight and volume were also determined.

The ECLSS for the EMCC Space Station Freedom (SSF) configuration consist of six functional areas, each having multiple subsystems, as shown in Exhibit 2.5.2-1. The technologies described in the database are limited to Atmosphere Revitalization (AR) and Water Recovery and Management (WRM). The subsystems described in the database are CO₂ removal, CO₂ reduction, O₂ generation, urine processing, and water processing, as shown in Exhibit 2.5.2-1. Exhibit 2.5.2-2 is a list of the technologies included in the database. This exhibit shows the functions of each technology and their related ECLSS subsystem.



** Functional Areas Covered by the Technologies Database

Exhibit 2.5.2-1. SSF ECLSS for the EMCC Configuration

ECLSS Subsystem	Function	Technologies
AR	CO ₂ Removal	4-Bed Molecular Mole Sieve (4BMS)
		2-Bed Molecular Mole Sieve (2BMS)
		Lithium Hydroxide Canisters (LHOH)
		Solid Amine Water Desorbed (SAWD)
		Electrochemical Depolarized CO ₂ Concentrator (EDC)
		Air Polarized CO ₂ Concentrator (APC or EDC W/WO H ₂)
	CO ₂ Reduction	Bosch Sabatier Advanced Carbon Reactor (ACR)
	O ₂ Generation	Static Feed Water Electrolysis (SFWE) Solid Polymer Electrolysis - Liquid Anode Feed (SPE) Water Vapor Electrolysis (WVE)
	O ₂ Generation/CO ₂ Reduction	CO ₂ Electrolysis
WRM	Urine Recovery	Thermoelectric Integrated Membrane Evaporation Subsystem (TIMES)
		Vapor Compression Distillation (VCD)
		Air Evaporation System (AES)
		Vapor Phase Catalytic Ammonia Removal (VPCAR)
	Water Processing	Reverse Osmosis (RO) Multifiltration (MF) Electrodeionization

Exhibit 2.5.2-2. Technologies Included in the Technology Database

The related technologies can be better compared with each other by defining the logistics requirements, power penalty, heat rejection penalty, unit weight and volume, launch weight and volume, and operation life. Task 3 focused on defining the logistics requirements for each technology. However, due to a lack of detailed resupply information, the logistics requirements defined for the technologies are not sufficient to provide as meaningful analysis results as could be determined from a more comprehensive study. In order to develop meaningful logistics requirements and perform a more detailed logistics analysis and trade studies for each SSF evolution for each ECLSS technology, task 3 focused on the development of procedures for data collection, logistics analysis, and logistics trade studies, as described in the task flow shown in Exhibit 2.5.2-3.

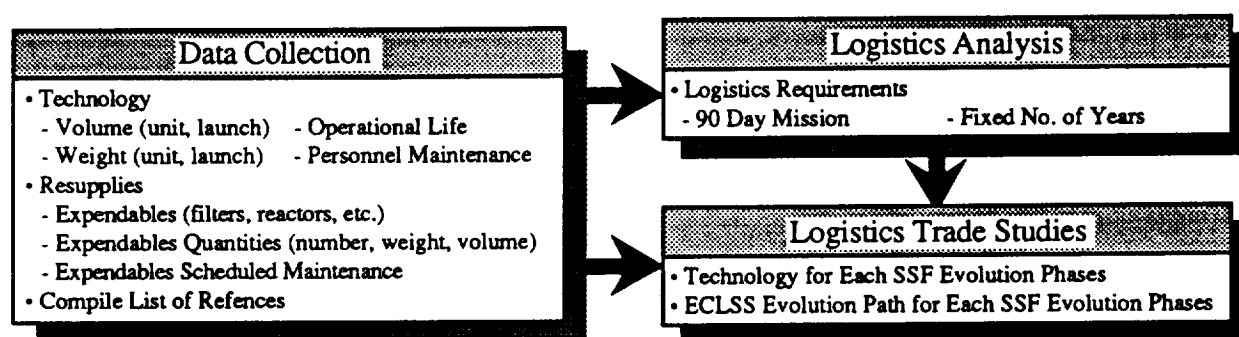


Exhibit 2.5.2-3. Technologies Logistics Study Task Flow

Logistics requirements for each technology are based on resupply requirements and parameters that govern the transportation of the resupply items. The type of data to be collected can be broken down into categories, such as types of resupply expendables (filters, reactors, bottled gas, etc.), quantity of expendables, volume and weight (resupply, return, launch) of expendables, mean time between failures of expendables or operational life time, etc. In addition to these data categories, consideration should be given to the logistics involved with any special transportation environmental requirements (storage constraints - dimensions, temperature, power), special transportation packaging hardware, and personnel time required for maintenance. Exhibit 2.5.2-4 shows a comparison of some of the higher level data collected for each of the technologies from two separate references. Due to inconsistencies in collected data, it was determined that 3 to 4 references should be used, if possible, to compare and verify the data collected. These inconsistencies can cause substantial error in the logistics analysis and trade studies. The information collected should then be summarized in a database to provide analysis capabilities in order to quickly perform logistics analysis and trade studies for the ECLSS technologies. Sources containing the required data for each technology should be compiled in a list for future reference and more detailed analysis.

ELCSS Technologies	Manrate (Person)		Weight (lb)						Volume (ft3)			
			Unit	90 Day				Unit	90 Day			
				Resupply		Return			Resupply	Return		
	Ref 1	Ref 2	Ref 1	Ref 2	Ref 1	Ref 2	Ref 1	Ref 2	Ref 1	Ref 2	Ref 2	Ref 2
4BMS	4	8	246	425	---	0		0	14.0	33.1	0	0
2BMS	4		180		---				13.0			
LiOH	4		17		1176				2.0			
SAWD	4		228		3				14.0			
EDC	4		169		---				5.0			
APC	4		190		---				6.0			
Bosch	4	8	725	689	377	205		637	32.4	39.1	21.8	21.8
Sabatier	4	8	114	114	264	0		0	2.4	2.4	0	0
ACR	4		600		24				23.0			
SFWE	4	8	160	160	---	---		---	3.6	---	---	---
SPE	4		230		---				6.0			
WVE	4		119		---				3.0			
CO2 Electrolysis	4		166		---				4.0			
TIMES	8	8	225	665	683	42		672	10.3	30.4	9.16	9.16
VCD	8		330		930				13.4			
AES	3		200		68				---			
VPCAR	8		300		800				18.0			
RO	8	8	566	1373	233	284		284	22.5	33.8	2.38	2.38
MF	8	8	160	1092	112	112		112	12.4	59.9	1.10	1.10
Electrodeionization	--		30		---				2.0			

Reference 1 - "Advanced ECLSS Subsystem and Instrumentation Technology Study for the Space Exploration Initiative", McDonnell Douglas Space Systems Co., Contract NAS8-36407, October 1990.

Reference 2 - Pre-Turbo SSF ECLSS Data received from Paul Wieland, NASA-MSFC, November 1990.

Exhibit 2.5.2-4. Some ECLSS Technologies Logistics Related Characteristics

Once sufficient data is collected, logistics requirements for each technology can be determined. This can be accomplished by using the resupply requirements, maintenance requirements, component operational life and operational capabilities data to calculate the logistics requirements for a given crew size and resupply period. By accounting for a technology's unit weight and volume, its operational life, and the major components' operational life, the technology's logistics requirements can be analyzed based on a set number of years. This would allow the related technologies to be compared based on total logistics requirements of transportation and maintenance for an extended length of time, such as the planned operational life time of the SSF. The technologies logistics data should then be summarized with a listing of any special transportation requirements that would require additional logistics.

From the information collected and the logistics requirements defined, various trade studies could be performed for better characterization and comparison of the related ECLSS technologies. These trade studies should include a study to determine the logistics requirements of the technologies based on each proposed SSF evolution configuration in which there will be different crew sizes. This study should involve defining the logistics requirements per 90-day resupply mission and total logistics requirements for a set number of years. Special consideration should be

given to "economies of scale," such as reduction of total resupply logistics requirements per technology given an increase in the number of crews.

With the information developed from the resupply and logistics requirements study, an evaluation of the total logistics requirements for each SSF evolutionary configuration path could be conducted. An example task flow for this type of study is shown in Exhibit 2.5.2-5. This study might include determining proposed ECLSS evolutionary paths (technology combinations and proposed technology upgrade or replacement) for each SSF evolutionary configuration path. The study should not include combinations of functionally related technologies, such as Bosch or Sabatier for CO₂ reduction, due to lack of commonality and increased logistics requirements. These trade studies would provide meaningful results that can be better used for determining the ECLSS configurations and evolution paths that minimize total ECLSS logistics requirements.

In order to reduce the logistics requirements for each technology (unit volume and weight, resupply requirements, etc.), consideration might be given to some of the issues shown in Exhibit 2.5.2-6. The first two issues could be addressed through ventilation trade studies similar to the studies performed in task 1 of this contract. The later two issues would require detailed knowledge of the design, operations, and performance of each technology. Therefore, the later two issues might be better addressed by the developer of each ECLSS technology.

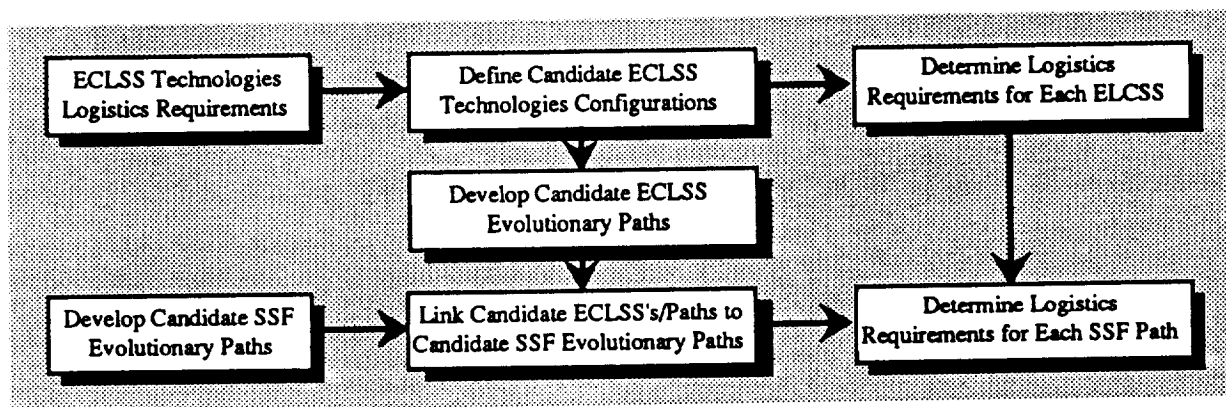


Exhibit 2.5.2-5. Logistics Trade Study Task Flow for ECLSS Evolutionary Paths

1. Can the number of AR's required be reduced through improved ventilation and selection of optimum locations?
2. Should limitations be placed on the personnel concentration per area?
3. Can design modifications be made to improve performance?
 - Extended components operational life
 - Reduced weight and volume per unit or components
 - Increase man-rate limit to reduce the number of required units and resupplies
4. Can operations be simplified to reduce maintenance and resupply requirement?

Exhibit 2.5.2-6. Logistics Requirement Reduction Issues

2.5.3 Results

The primary work accomplished under this task was a cursory evaluation of the ways to reduce logistics weight and volume. One recommendation from the cursory evaluation is to place the THCS for the logistics module in the node it attaches to. This would eliminate the need to repeatedly launch and return the THCS and would therefore allow more resupply mass and volume to be carried on the logistics module. A complete report is presented in Appendix D.

2.6. Task 5 - ECLSS Evolution: Module Addition Relocation

2.6.1 Statement of Task

The purpose of this task was to evaluate aspects other than ventilation as modules are added or relocated and as interior rearrangements are made. This task is an extension of the intermodule ventilation trade studies. Furthermore, this task involved development of ECLSS growth concepts consistent with SSF's growth phases and identified impacts such as additional interconnections required and other effects. Refer to section 2.3.1-1 for the SOW section related to this task.

2.6.2 Description of Work

The following assessment identified studies recommended to insure that critical resources and ECLSS functional requirements are maintained during station configuration changes and evolutionary growth, including module addition and relocation, and that safe haven requirements are also met for each evolving configuration and during configuration changes. Examples of growth configurations that require analysis are described in Task 1 SSF Evolution Concepts Ventilation Trade Studies. Crew safety requirements are contained in SSP 30000 Section 3

Revision K. The following quote is from SSP 3000 Section 3 Revision K: "In general, station systems functions which are essential for crew safety and station survival shall be two failure tolerant as a minimum (except for primary structure and pressure vessels in the rupture mode). During initial station assembly and periods of maintenance these systems functions shall be single failure tolerant as a minimum and on-orbit restorable. Table 3-2.2 from SSP 30000 Section 3 Revision K, provides functional failure tolerance requirements. The space station shall provide the capability to isolate any element containing a catastrophically hazardous event from the remainder of the Space Station. In the event of any single failure, including the complete loss of one pressurized element, the space station shall provide safe haven capabilities to insure crew survival for a maximum duration of 22 days." Exhibit 2.6.2-1 contains table 3.2-2 from SSP 30000 Section 3, revision K.

TABLE 3-2.2 SSMB FUNCTIONAL FAILURE TOLERANCE REQUIREMENTS

FUNCTION	PRIME SUPPORTING SYSTEM ⁴	CATEGORY	REQUIRED FAILURE TOLERANCE ^{1,2,3,7}	
			MTC	PMC
Provide Safe & Healthy Working Environment				
1.1 Respirable Atmosphere				
1.1.1 O2 Generation/O2 Supply	ECLSS	1C	N/A	2
1.1.2 O2/N2 Storage	ECLSS	1C	1	2
1.1.3 O2/N2 Distribution	ECLSS	1C	1	2
1.1.4 O2/N2 Pressure Control	ECLSS	1C	1	2
1.1.5 CO2 Venting (PMC)/Reduction (AC)	ECLSS	1C	0	2
1.1.6 CO2 Removal	ECLSS	1C	0	2
1.1.7 Air Particulate & Microbial Control	ECLSS	1C	1	2
1.1.8 Cabin Air Temperature and Humidity Control	ECLSS	1C	1	2
1.1.9 Circulation	ECLSS	1C	1	2
1.1.10 Vent & Relief	ECLSS	1C	1	2
1.1.11 Atmosphere Composition Monitoring	ECLSS	1C	0	2
1.1.12 Trace Contaminant Monitor	ECLSS	1C	N/A	2
1.1.13 Trace Contaminant Control	ECLSS	1C	0	2
1.2 Operational Lighting				
1.2.1 General Lighting	Element Unique	2	1	1
1.2.2 Task Lighting	Element Unique	3	0	0
1.3 Acoustics				
1.3.1 Hearing Conservation Acoustic Control	Element Unique	3	0	0
1.3.2 Severe Discomfort Vibration Control	Element Unique	3	0	0
1.4 Food				
1.4.1 Food Storage	MS	1C	N/A	2
1.4.2 Food Preparation	MS	2	N/A	1
1.4.3 Food Waste Collection/Storage	MS	2	N/A	1
1.5 Water (Potable/Hygiene)				
1.5.1 Water Storage	ECLSS	1C	N/A	2
1.5.2 Water Processing	ECLSS	1C	N/A	2
1.5.3 Water Thermal Conditioning	MS	3	N/A	0
1.5.4 Water Distribution	ECLSS	2	N/A	1
1.6 Personal Hygiene				
1.6.1 Reserved				
1.6.2 Full Body Cleansing	MS	3	N/A	0
1.6.3 Handwash/Partial Body Cleansing	MS	2	N/A	1
1.6.4 Urine Collection	ECLSS	1C	N/A	2
1.6.5 Urine Processing	ECLSS	2	N/A	1
1.6.6 Urine Storage	ECLSS	1C	N/A	2
1.6.7 Urine Removal	ECLSS	2	N/A	1
1.6.8 Fecal Waste Collection	ECLSS	1C	N/A	2

¹When present prior to PMC, the Space Shuttle may be considered as an additional path of redundancy to this table.

²Requirements apply from the primary stage listed up to, but not including, the next primary stage.

³In circumstances where a conflict exists between required failure tolerances, the most stringent requirement takes precedence.

⁴This column is intended to add clarity to the function descriptions. It is not a requirement nor a part of the functional partitioning.

⁵Failure tolerance for specific applications is achieved by superposition of these functional failure tolerance requirements with the safety failure tolerance requirements.

⁶These functions shall be one failure tolerant at PMC minus one assembly flight.

⁷For PMC and following, crew survival functions may achieve two failure tolerances by using the ACU/ in lieu of a redundant path.

⁸Those Category 1 functions that are shown to be time critical may be required to be 2 failure tolerant.

Exhibit 2.6.2-1. Table 3-2.2 from SSP 30000 Section 3 Revision K

ECLSS functions recommended for assessment to meet redundancy and safe haven requirements for each evolving configuration including module addition and/or relocation (excluding intermodule ventilation) are as follows:

- O₂/N₂ storage and distribution
- Cabin air temperature and humidity control (including avionics air cooling)
- Trace contaminant control
- Water storage and processing and distribution
- Urine processing storage
- Fecal waste collection
- Food storage

A study approach overview applicable to each of the above ECLSS functions is shown in Exhibit 2.6.2-2. In each case the ECLSS requirements from the applicable documents should be used to develop study groundrules and requirements. Once the requirements are understood and a specific configuration has been selected the assessments can be made by developing a subsystem model and applying the model to the specific configurations or constraints of interest. The results including issues and recommendations can be reported and documented as indicated in the Exhibit 2.6.2-3.

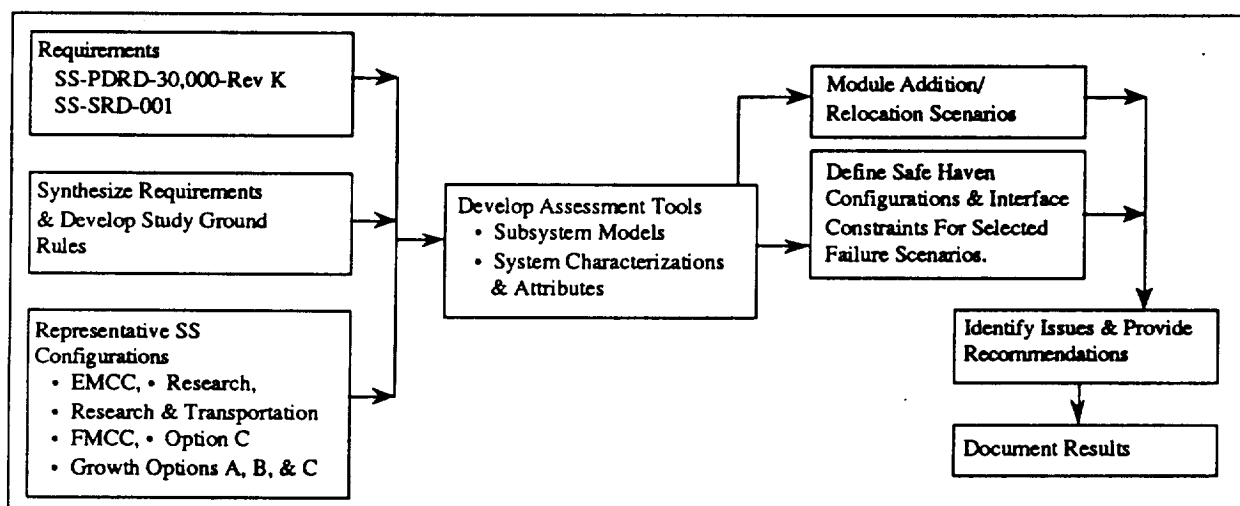


Exhibit 2.6.2-2. Study Approach Overview

ECLSS Function	Recommended Study
O ₂ /N ₂ Distribution	<ul style="list-style-type: none"> • Evaluate Space Station Build Up Scenarios • Evaluate Capability For Safe Haven Rqmts And Skipped Resupply • Identify Best Distribution Of Stored O₂/N₂ To Minimize Impacts Of Catastrophic System Loss
Cabin Air Temperature and Humidity Control	<ul style="list-style-type: none"> • Evaluate Function Distribution To Assure Safe Haven Rqmts Are Satisfied • Evaluate System Performance & Function Distribution To Assure That Space Station Growth Configurations & Build Up Scenario Requirements Can Be Satisfied • Evaluate System To Investigate Feasibility Of Removing Temperature & Humidity Control Equipment From Logistics Modules
Trace Contaminant Control	<ul style="list-style-type: none"> • Evaluate Trace Containment Control & Monitoring Capability For Configurations Build Up & Failure Scenarios Requiring A Safe Haven - Identify Distributions Of Monitoring And Control Equipment That Support Build Up And Safe Haven Requirements.
Water Storage, Processing, and Distribution	<ul style="list-style-type: none"> • Determine Adequacy Of Water Distribution System To Provide Redundant Paths To Accommodate Failure, Or Removal Of A Pressurized Module • Determine Capability To Accommodate Loss Of Processing Capability And Water Due To Loss Or Removal Of A Pressurized Modules
Fecal Waste Collection	<ul style="list-style-type: none"> • Assess Adequate Distribution Of Fecal Waste Collection Systems To Assume Safe Haven Requirements Can Be Met
Food Storage	<ul style="list-style-type: none"> • Assess Food & Equipment Distributions For Each Growth Configuration To Assure That Safe Haven Requirements Can Be Satisfied
System Study	<ul style="list-style-type: none"> • Combine The Results Of The Previous Studies And Other Information As Required To Define A Safe Haven Configuration For Each Growth Configuration And Failure Scenario

Exhibit 2.6.2-3. Summary of Recommended Studies

O₂/N₂ Storage and Distribution

The PDRD 30000 Rev. K requires a Safe Haven for 22 days. A skip cycle or missed resupply requires 90 days of atmosphere gas. This includes 45 days of normal operation plus 45 days "safe mode" plus three, two person EVAs plus one hyperbaric treatment. A CR to revision K increases the crew survival requirements to 45 days, and provides for a delayed resupply of 90 days.

Based on atmosphere gas allocations (user requirements), resupply capabilities (cryo tankage storage capabilities and residuals, etc.), and the above requirements the capability of the system to meet the requirements can be assessed. From a brief review of the PDRD requirements there appears to be no requirements for distributing the stored gas such that a catastrophic event causing the loss of one storage system could be accommodated. In other words there is no backup gas storage system onboard the station. As the space station grows in crew and elements, a study

objective could be to evaluate the benefits of distributing the gas storage to minimize the effects of losing one set of storage tanks, and to insure that safe haven and skip cycle requirements can be met for all growth configurations.

Cabin Air Temperature and Humidity Control

The temperature and humidity control system must be capable of meeting the safe haven requirements, and also have the flexibility to accommodate module additions and relocations.

These top level requirements and space station growth configuration characteristics will allow definition of thermal loads (crew and equipment and structural heat leak). A TRASYS/SINDA thermal model may be needed to evaluate the structural heat transfer, for the evolving configurations. A coolant loop model including the sensible and latent heat removal characteristics of the heat exchangers can be formulated to predict atmosphere temperatures and humidities for various build up scenarios and failure conditions.

These models can be used to assess the thermal control system capabilities for various configurations, failures, and build up scenarios. Study objectives would be to assess the configurations' build up scenario to determine that the thermal control system can meet temperature and humidity requirements; assess various failure scenarios and determine the optimum "safe haven" configuration for each failure case, and finally to evaluate for each configuration the need to provide heat exchanges in logistics modules. Fixed equipment weight and volume in the logistics modules is very expensive because it is launched repeatedly.

Trace Contaminant Control

Trace contaminants are controlled and monitored in the habitable environment. Short term maximum allowable concentrations, and continuous maximum allowable concentrations are specified. These requirements and the failure tolerance and safe haven requirements determine the trace contaminant control performance requirements for the various configurations and build-up scenario.

A system model similar to the intermodule ventilation model should be developed to assess the trace contaminant control system performance under various conditions. It may be desirable to add a transient capability to the model to evaluate recovery times for various failure scenarios. This capability would allow evaluation of the best distribution of control and monitoring equipment for each configuration and failure scenario. Study objectives would be to determine safe haven configurations for failure scenarios, and optimum locations of control and monitoring equipment to meet safe haven and build up scenarios.

Water Storage Processing and Distribution (Including Urine Collection Processing and Storage)

Failure tolerance requirements must be met for potable and hygiene water during space station configuration evolution. The system must also accommodate safe haven requirements. In the event a pressurized module is functionally lost due to removal or failure, the water distribution system must have redundant paths to provide resources to the remaining habitable volumes. The removal or loss of a module may involve water loss, and loss of water processing storage and recovery capability. The impacts of this loss can be assessed for each failure scenario, and/or configuration change.

The objectives of this study would be to determine the adequacy of the water distribution system to by pass disabled modules, and to provide sufficient reserve capability to accommodate water losses that could be associated with module losses. The study should also identify safe haven configurations for selected failure scenarios for each of the growth configurations.

Fecal Waste Collection

Each of the growth configuration failure scenarios involving the loss of pressurized modules will require identification of a safe haven configuration. The safe haven configuration should contain a fecal waste collection capability to support the entire crew. Assessments should be made to identify adequate distribution of fecal waste collection systems to assure that safe haven requirements are satisfied.

Food Storage

Safe haven provision requirements require food and equipment to be available in the remaining pressurized volume for a period of 22 days (SP 30000 Revision K), or 45 days (CR to Revision K).

An assessment to determine food and equipment distribution for each growth configuration should be made to assure these requirements are satisfied.

System Study

Shown in Exhibit 2.6.2-3 is a summary of study recommendations. The results from evaluating each subsystem should be combined with other requirements, such as access to escape vehicles, recovery of EVA personnel etc., to define a safe haven configuration for each of the growth station configurations. Although intermodule ventilation analysis was not performed under this task, the air distribution system characteristics and capabilities should be included in the overall system assessments to identify safe haven configurations and in investigating the buildup scenarios.

2.6.3 Results

Studies were identified to be performed to ensure that critical resources and ECLSS functional requirements are maintained during module configuration changes and evolutionary growth. No results from addition and relocation studies are available due to insufficient resources being available to perform the identified studies. A complete report on the work accomplished under this task is presented in Appendix E.

2.7 Task 6 - ECLSS Evolution: "Hooks and Scars" Study and Cost/Benefit Analysis

2.7.1 Statement of Task

The purpose of task 6 was to identify the rack level interface requirements of the alternative technologies evaluated in Task 1 and compare these with the rack level interfaces for racks with the baseline technologies. Those technologies which require rack level interfaces not required by the baseline technologies were to be identified and the additional interfaces required were to be defined. Furthermore, the cost of implementing the identified "hooks and scars" including the costs of tubing, ducting, wiring, power, etc. were to be evaluated and compared with the benefits of reduced resupply, increased capabilities, simplified operation, reduced maintenance needs, etc. This effort is dependant on the availability of the results of the SSF restructuring activity to provide information on the baseline locations of ECLS subsystems, the interfaces provided, and the scars provided to accommodate EMCC. Refer to Exhibit 2.3.1-1 for the SOW relating to this task.

2.7.2 Description of Work

The purpose of this task was to identify the rack-level interface requirements of the alternative technologies evaluated in Task 2 and compare these with the rack-level interfaces requirements for the baseline technologies. This involved identifying those technologies which require rack-level interfaces not required by the baseline technologies and defining the additional interfaces required. This effort was dependent on the availability of the results of the Space Station Freedom restructuring activity to provide information on the baseline locations of ECLSS subsystems, the interfaces provided, and the scars provided to accommodate the EMCC configuration. The analysis performed under this task was focused on a specific Atmosphere Revitalization (AR) subsystem, O₂ Generation, in order to identify the rack-level interface "hooks and scars" requirements for the replacement of the EMCC baseline SFWE technology with the SPE technology.

In order to perform a comparative evaluation of the alternative ECLSS technologies rack-level requirements with the baseline technologies requirements, the baseline technologies were

identified and are listed in Exhibit 2.7.2-1. Based on the information gathered, the technologies represented in the Technology Interface Database (developed in Task 2), and given baseline technologies, the comparative analysis was conducted on the O₂ Generation AR subsystem. These O₂ generation subsystems include the baseline technology, Static Feed Water Electrolysis (SFWE), and an alternative replacement technology, Solid Polymer Electrolysis (SPE).

ECLSS Subsystem Category	Baseline Technology
CO ₂ Removal	4-Bed Molecular Mole Sieve (4BMS)
CO ₂ Reduction	Sabatier
O ₂ Generation	Static Feed Water Electrolysis (SFWE)
Urine Recovery	Vapor Compression Distillation (VCD)
Water Processing	Multifiltration (MF)

Exhibit 2.7.2-1. ECLSS Baseline Technologies for the EMCC Configuration

The rack-level interface requirements were identified for the SFWE and SPE ECLSS technologies from information found in the Interface Technologies Database and the ECLSS Technology Demonstrator Program (TDP) documentation. Exhibit 2.7.2-2 summarizes the basic rack-level requirements for the fluid and electrical interfaces, respectively, and presents a comparison between the related interface for each technology. The information shown in this exhibit provides a good understanding of the interface commonalities of these two ECLSS technologies.

In reference to the information shown in Exhibit 2.7.2-2, the number of required "hooks and scars" and interface issues were considered minimal due to the interface compatibilities between baseline and the alternate technology. In fact, the types and number of SFWE and SPE fluid interface input and outputs are the same, with the exception of additional liquid coolant and primary power connections required by the SFWE system. As shown in this exhibit, almost all of the fluid interface connections are identical, with the exception of some of the operation requirement for the lines and connectors. These exceptions can be planned for in the ECLSS evolution by selection of lines and connectors with operational parameters high enough to meet both technologies interface requirements. Electrical interface requirements for both SFWE and SPE technologies can be met by designing the electrical rack-level interfaces to meet the maximum power distribution requirements of both technologies. Due to the commonalities between the electrical input configuration of the two systems, this would require retaining the RS232C cables, and replacement and removal some of the DC power cables when the SFWE technology is replaced with the SPE technology.

ELECTRICAL INTERFACES		TECHNOLOGY			
		SFWE (Baseline)		SPE (Candidate Replacement)	
		Requirement	Connector	Requirement	Connector
Primary Power		28 VDC (30A)	TBD	28 VDC	MS27497E12F4PN (Plug)
Primary 60Hz Power		115 VAC (60Hz, 1Ø, 10A)	TBD	115 VAC (60Hz, 3Ø)	MS27497E14F5PN (Plug)
Primary 400Hz Power		115/208 VAC (400Hz, 3Ø, 25A)	TBD		
CCDS Communication		RS232C Protocol	TBD	RS232C Protocol	MS27497E10F35SN (Socket)

FLUID INTERFACES (Liquid & Gas)		PRESSURE (psia)		TEMPERATURE		FLOW (lb/day)		Fitting Type	Fitting Size (in.)
		Nominal	Range	Nominal	Range	Nominal	Range		
INPUTS	H ₂ O Feed	32 35	30-35 35-40	70 Ambient	60-80 60-120	12.78 12.48	216-16.56	O-Ring Seal Compression	1/4 1/4
	N ₂ Supply (O ₂ Side)	182	180-185	70	60-80	0.076	0.076	O-Ring Seal	1/4
	(H ₂ Side)	182	180-185	70	60-80	included †	included †	O-Ring Seal	1/4
	(O ₂ & H ₂)	265	260-270	Ambient	Ambient-100	* 67 in ³	* 67 in ³	Compression	1/4
OUTPUTS	O ₂ Product	20 20	14.5-25 Ambient-230	70 120	60-85 Ambient-130	11.12 11.04	192-14.64	O-Ring Seal O-Ring Seal	1/4 1/2
	H ₂ Product	20 25	14.5-25 Ambient-195	70 120	60-85 Ambient-130	1.39 1.39	024-1.85	O-Ring Seal O-Ring Seal	1/4 1/4
	O ₂ Vent	14.7 Ambient	0-20 Ambient-230	80 120	70-95 Ambient-130		* 8.5 in ³ * 8.5 in ³	O-Ring Seal O-Ring Seal	1/4 1/2
	H ₂ Vent	14.7 Ambient	0-20 Ambient-195	80 120	70-95 Ambient-130		* 73 in ³ * 73 in ³	O-Ring Seal O-Ring Seal	1/4 1/4
	Liquid Coolant	25	14.5-30	44	42-46	12k	9.6k-14.4k		

* @ Start-Up



 BASELINE TECHNOLOGY
Static Feed Water Electrolysis (SFWE)
  CANDIDATE REPLACEMENT TECHNOLOGY
Solid Polymer Electrolysis (SPE)

Exhibit 2.7.2-2. Comparison of Fluid and Electrical Interfaces for SFWE and SPE Technologies

In order to reduce the required number of "hooks and scars", the temperature and pressure requirements for each fluid interface should exceed the highest value of the two technologies by a predefined safety factor. The initial designed input pressure for the H₂O and N₂ supply should be based on the higher SPE technology requirements and then regulated down to the required pressure for the baseline SFWE technology. This will provide for easier deregulation on the supply pressures and connection of the interfaces between the baseline and replacement technologies. The SFWE technology requires two N₂ supply lines, one for the O₂ side and the other for the H₂ side,

while the SPE technology requires only one N_2 supply line. This would require that one of the N_2 supply lines be plugged when the SFWE is replaced by the SPE. Also, the H_2O and N_2 system interface connector types are different and require either a transition connector be used between the rack interface line and the SPE system or that the rack interface line be replaced with a line containing a 1/4" compression fitting at one end, instead of the 1/4" o-ring seal fitting used with the SFWE system. Considerations should be given to the 1/2" O_2 product and vent lines and connectors to determine if 1/4" lines and connectors could be utilized, providing a small reduction in the "hooks and scars" requirements. The liquid coolant interfaces required for the SFWE system is not required for the SPE system and should be removed, due to the fact that the SPE system utilizes cabin air, which is blown through the system to dissipate heat generated by the system, and requires no interfaces.

As mentioned above, the electrical interface requirements for both SFWE and SPE technologies can be met by designing the electrical rack-level interfaces to meet the maximum power distribution requirements of both technologies. The types of electrical interface connectors were not specified for the SFWE system and, therefore, could use the same type of interface connectors used by the SPE system. This can be accomplished by using the same connectors but with only the required pin configuration for each electrical interface for the given technology. Both technologies require basically the same primary 28 VDC interfaces. The 115 VAC power requirements will be changed to 28 VDC for the final flight version of each technology. When the SFWE system is replaced with the SPE system, a DC power cable should be removed and its connectors, on the rack interface plate, should be plugged to guard against any shorting. The SFWE system's RS232C rack interface connection requires only three of the normal RS232 data lines, where the SPE system requires seven of the data lines for Command, Control, and Display Subsystem (CCDS). Since both technologies use the same data line configuration, RS232C protocol, the same cable can be used for CCDS communications for both technology systems.

In addition to these "hooks and scars" issues, a related issue is the heat load penalties for both technologies on the Space Station. The SFWE system dissipates 648 BTU/HR to the cabin air heat exchanger and 737 BTU/HR to the station's cold plate heat exchanger, while the SPE system dissipates 1307 BTU/HR from the electrolysis assembly and 3901 BTU/HR from the electrolysis cell stack DC power to the cabin air heat exchanger. The SPE technology shows definite heat load penalties placed on the Space Station.

The EMCC AR baseline technology for O_2 generation, SFWE, and one of its alternative replacement technologies, SPE, was found to provide many interchangeable fluid and electrical rack-level interface, due to the related technologies interface commonalities. With a minimal number of rack-level "hooks and scars" identified, the SFWE technology could be replaced with the SPE technology. A summary of the rack-level interface "hooks and scars" for the replacement

of the SFWE technology with the SPE technology is shown in Exhibit 2.7.2-3. In addition, one issue that should be considered is the heat load penalty placed on the Space Station by this ECLSS technology evolution.

- Provide a 1/2" to 1/4" Reduction Line for the O2 Product and Vent Outputs
- Provide an O-Ring Fitting to Compression Fitting Transition line for H2O and N2 Supply Rack Interfaces for the SPE Technology
- All Fluid Interface Lines and Connectors Should Accommodate the Higher Operational Pressure and Temperature Requirements of the SPE Technology.
- Provide Plugs for the Rack Interface Connector for the DC Power Sources and Liquid Coolant sources
- Remove DC power cables and Liquid Coolant lines that are not needed
- Provide a Complete RS232 Rack Connection and Cable Configuration

Exhibit 2.7.2-3. Rack-Level Interface "Hooks and Scars" Summary for Replacement of SFWE Technology with SPE Technology

2.7.3 Results

The work accomplished under this task included limited analyses which were performed comparing the Solid Polymer Electrolysis O2 generation subsystem with the baseline Static Feed Water Electrolysis Subsystem. The results are examples of the types of "hooks and scars" required to accommodate the alternative technologies. For some alternative technologies relatively minor accommodations will allow the flexibility to incorporate them. Additional data on the other technologies is scarce and more time is required to gather this data. The procedures for performing a cost/benefit analysis has been developed but no results are available. This analysis depends on additional data on the technologies which is scarce and more time is required to gather this data. Appendix F is a full report of the work done under this task.

2.8 Task 7 - Advanced Instrumentation: Technology Database Enhancement

2.8.1 Statement of Task

The purpose of this task was to add to the database of instrumentation and sensors, including providing more information on the instruments and sensors already listed and adding information about other instruments and sensors applicable to P/C ECLSS or CELSS which were not previously included. The section of the SOW relating to technology database enhancement is presented below in Exhibit 2.8.1-1. The "bold face" type reflects the contract modification to enhance the Sensors Database. Also refer to Exhibit 2.2.1 for further clarification of Sensors Database related SOW tasks.

b. ALS DATA BASE DEVELOPMENT

The existing ALS data base shall be expanded in scope and depth to include all candidate life support technologies and, at a minimum, all parameters outlined in COMPUTER TOOL DEVELOPMENT below for use in computer modeling. In addition, the existing data of sensors applicable to ECLSS shall be expanded and sufficient information on each sensor included to support the tasks outlined below in task e.2. REAL-TIME SENSORS. Selection of a data basing tool will be chosen by the contractor (with MSFC concurrence)."

Exhibit 2.8.1-1 Section of the SOW Related to Technology Database Enhancement**2.8.2 Description of Work Done**

The purpose of this task was to add to MDSSC Sensors Database, including providing additional information on the instruments and sensors described in the database and adding information about other instruments and sensors applicable to P/C ECLSS or CELSS which were not previously included. The Sensors Database was reviewed in order to determine the types of data required, define the data categories, and develop an understanding of the data record structure. An assessment of the MDSSC Sensors Database identified limitations and problems in the database. Guidelines and solutions were developed to address these limitations and problems in order that the requirements of the task could be fulfilled. Following the guidelines set forth, the MDSSC Sensors Database was broken into smaller relational databases based on sensor types shown in Exhibit 1, data fields not applicable to a given sensor type were deleted, some additional fields were added, and new report forms were made for each sensor database to present the only relevant information in report form. The sensor data was verified, additional sensor data information was added, sensor operational specification data in each description category was converted to one standard unit, new references were added, and new sensor technologies were added to some of the sensor type databases. In addition to these changes, Appendices B through H documentation was created in order to replace the Appendices B through H (Sensor Database) in McDonnell Douglas Space Systems Company report entitled "ECLSS Integration Analysis - Advanced ECLSS Subsystem and Instrumentation Technology Study for the Space Exploration Initiative". As shown in Exhibit 1, each appendix is representative of a given sensor type database. These appendices include the information printed out on the new report form, sensor figures on new figure report forms, sensor and figure listing, an additional reference summary, and MCDSSC's original brief sensor type description.

SENSOR TYPE	Appendix	Number of Sensor Technologies	
		MDSSC Database	New Database
Microbial	B	17	17
Chemical	C	32	32
Conductivity	D	3	3
Flow Measurement	E	11	11
Moisture/Humidity	F	9	11
Pressure	G	10	12
Temperature	H	7	9

Exhibit 1. Sensor Types Included in MDSSC Sensors Database

An assessment of the MDSSC Sensors Database identified limitations in the database record structure. It was determined that the record definitions, in general, were usable but misleading or incomplete. The database was designed as a general instrumentation and sensors database in which all 90 sensor technologies entries were given the same descriptive data fields. Many of the data fields were not applicable to a given sensor type and many of the fields that required numeric inputs were defined as a character fields in order to allow for proper unit notation for a given sensor type. This database design provide some search and sort capability, but substantially limited detailed search and sort capabilities that are common for most computerized databases due to the inability of databases to search for a given numeric range in a character field. The information for each instrumentation or sensor from this database was presented in a general report form. This required presenting data information that was not applicable for a given sensor type and was represented as "---" in the data fields of the report form. Many data fields could only be a value for a particular sensor design. It was determined that some general philosophies for building databases were not used, such as 1) enter data at lowest level, and 2) several small relational databases are better than one large conglomerate database.

In order to provide a more useful database, SRS recommended working within the existing Sensors Database structure and developing guidelines for entering data. After further consideration, guidelines for modification of the database structure were developed. The guidelines are 1) retention of all existing data, 2) creation of separate, but relational, databases per sensor type, 3) creation of unique record structures per sensor type including the deletion and/or addition of data fields, and 4) creation of unique report forms, input forms, indexes, etc. per database. These guidelines were implemented in order that the modifications could be made allowing for easier and or meaningful data entry and database operations.

In addition to changing the record structure, the data in each sensor database was verified and modified, if required. Additional references were used in order to verify the sensor operational data entered and to provide additional sensor information. The additional information included a more detail description of operational parameters, such as ranges, and important operational concerns (performance, environment, etc.). The variables used in the previous performance equations were defined and additional technology performance equations, with their variable descriptions, were added. The operational class description was changed for some sensor technologies to make them consistent with the operational class described in the MDSSC Sensor Database manual. Some of the data fields were deleted and some were modified in order to develop an independent but relational database. The non-applicable fields were deleted so that unrelated data fields for the temperature sensor types would not be shown in the input data forms. Some of the character fields were modified by increasing or decreasing in size to allow for additional information and changed to numeric fields to allow for more detailed database search and sort capabilities. In order to present only the information related to a specific temperature sensor technology, a new report form was developed. These report forms are similar to the report form used for MDSSC Sensors Database, due to customer's information requirement needs, but with the exceptions of increased description and reference fields size, the omission of non-applicable sensor data fields and information, and addition of relative data fields.

Each sensor database originally included a number of sensor technology rating categories (Automation, Reliability, Development Potential, and Score) for which rating or scaling schemes were not describe in the MDSSC sensor database documentation. These categories can provide a very useful means for comparison of the various related sensor technologies for a given ECLSS subsystem technology. Therefore, the rating schemes for each category should be defined and the ratings information entered into each sensor databases. The sensor information report forms can then be easily modified in order to include ratings information.

The appendices (B through H), included in the main appendix of this document, are to be used as a replacement for the sensor database appendices (B through H) in McDonnell Douglas Space Systems Company (MDSSC) report entitled "ECLSS Integration Analysis - Advanced ECLSS Subsystem and Instrumentation Technology Study for the Space Exploration Initiative". All format and page numbering schemes used by MDSSC were used in the new sensor and instrumentation database appendices. The changes to the appendices include: new report forms print outs for each sensor type (or sensor database) with only relevant sensor type data included; updated and modified sensor data and information; additional sensor and instrumentation figures; new figure report forms; and a reference summary, located at the beginning of each appendix, for each sensor type. The new appendices were copied in a double sided format so that the sensor or instrumentation information and description report forms are always shown on the left hand side of

the document and corresponding sensor figure, if available, is shown on the right hand sided of the document. This will allow easy replacement or modification of sensor information and figures.

As noted on the new forms, some of the sensor data categories (Power, Weight, Volume, Operational Temperature Range, and Operational Pressure Range) are design specific data and should be entered into the database when it is made available. The information, that has already been entered into the database for these categories, includes some design specific data selected for a specified sensor. This information can be misleading, in many cases, and should be verified when each specific design case.

2.8.3 Results

The MDSSC Sensors Database was broken into smaller relational databases based on sensor types, data fields not applicable to a given sensor type were deleted, some additional fields were added, and new report forms were made for each sensor database to present the only relevant information in report form. The sensor data was verified, additional sensor data information was added, sensor operational specification data in each description category was converted to one standard unit, new references were added, and new sensor technologies were added to some of the sensor type databases. New Appendices B through H documentation was created in order to replace the original Appendices B through H (Sensor Database) in McDonnell Douglas Space Systems Company report entitled "ECLSS Integration Analysis - Advanced ECLSS Subsystem and Instrumentation Technology Study for the Space Exploration Initiative". As a result of this effort, a ECLSS related sensors and instrumentation database with a better computerized database capability and sensor specific report documentation than the original sensors database was provided to NASA.

2.9 Task 8 - Clean Room Survey and Assessment

2.9.1 Statement of Task

This task was added to the statement of work in order to survey cleanrooms to eventually support improvement capabilities for advanced ECLSS studies. Refer to Exhibit 2.3.1-1 ("**bold face**" type only) for SOW sections related to the Clean Room Survey and Assessment task.

2.9.2 Description of Work Done

The scope of the MSFC Clean Room Survey and Assessment task was to perform a comparative analysis of the various ECLSS evaluation options for different growth scenarios. The Space Station Freedom ECLSS Design and existing ground-based clean room facilities at MSFC were used as a baseline for comparison. The task involved an evaluation of the facilities,

equipment, technologies, and procedures used to maintain specified environments in typical aerospace industrial areas. The objectives of this task were twofold; first, to collect, compare, and catalog data for each specified facility including Engineering/Design, Construction Materials, Work Stations, Contamination Control, Particulate Elimination, Entry Systems, and Instrumentation and second, to formulate recommendations concerning enhancements required to assure an efficient and orderly evolution of MSFC Clean Room environmental control facilities.

2.9.3 Results

The SRS/NTS team conducted the on-site survey of the NASA MSFC cleanroom facilities on October 29, 1990 through November 4, 1990. The survey was conducted in accordance with FED-STD-209D, which calls out the various requirements for different classes of cleanrooms. A separate evaluation form was completed for each cleanroom surveyed. A complete report of this task is presented in Appendix H.

3.0 CONCLUSIONS AND RECOMMENDATIONS

Task 1, Evaluation of a CELSS, offers several conclusions, most notably is the fact that a 100% bioregenerative system is not practical. An appropriate mix of bioregenerative and physiochemical systems offers many practical solutions to providing life support for long duration space missions. Computer tools were built to support this task and working models were delivered to NASA.

Task 2 concluded that for the configurations evaluated, parallel ventilation flow appears to provide better misting of the air to maintain CO₂ concentrations in the acceptable range. Computer tools were built to support this task and working models were delivered to NASA. It is recommended that a transient analysis of intermodule ventilation be performed to determine the preferred flow path.

A database of ECLSS technologies interfaces was developed in task 3. Data was collected and entered for the well-defined technologies which were included in the Technology Demonstration Program at MSFC. Detailed data for other technologies was not readily available. Gathering additional data on the alternative technologies is recommended.

In task 4, a cursory evaluation was made of the ways to reduce logistics weight and volume. One significant conclusion from this study was that locating the PLM THCS in the attached node may be preferred to allow more mass and volume to be carried aboard the PLM. Performing a more detailed evaluation of locating PLM THCS in a node is recommended. Also, it is recommended that sufficient data to perform an accurate resupply analysis is gathered.

Tasks 5 identified studies to be performed to ensure that critical resources and ECLSS functional requirements are maintained during module configuration changes and evolutionary growth. The impacts on ECLSS due to adding or relocating modules should be evaluated.

Task 6 provided a limited analyses comparing the Solid Polymer Electrolysis O₂ generation subsystem with the baseline Static Feed Water Electrolysis Subsystem. The concluding remark was that relatively minor accommodations will allow flexibility in incorporating some alternative technologies. It is recommended that data should be gathered on additional technologies and that a cost/benefit analysis be performed.

Task 7 produced an verified, validated, and expanded set of sensors and instrumentation databases on pressure, temperature, moisture/humidity, conductivity, microbial, chemical, and flow measurement.

Task 8 produced survey results from the evaluation of 25 cleanroom facilities at MSFC.

4.0 REFERENCES

A complete list of references applicable to each individual task is presented with each task report in the Appendices.